Deeply–Virtual Compton Scattering on Deuterium and Neon at HERMES

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Abstract. We report the first observation of azimuthal beam–spin asymmetries in hard electroproduction of real photons off nuclei. Attributed to the interference between the Bethe–Heitler process and the deeply–virtual Compton scattering process, the asymmetry gives access to the latter at the amplitude level. This process appears to be the theoretically cleanest way to access generalized parton distributions. The data presented here have been accumulated by the HERMES experiment at DESY, scattering the HERA 27.6 GeV positron beam off deuterium and neon gas targets.

INTRODUCTION

Hard scattering processes, such as inclusive deeply–inelastic scattering (DIS), semi–inclusive DIS and hard exclusive scattering have an important property in common, namely the possibility to separate the exactly calculable perturbative parts of the reaction from the non–perturbative parts. This factorization property is well established in the case of inclusive and semi–inclusive DIS and has been extensively used to investigate the structure of the nucleon. Only a few years ago, factorization theorems have been established for some hard exclusive reactions, where the produced particle is e.g. a photon [1, 2, 3]. Their description in the theoretical framework of generalized parton distributions (GPDs) [4, 5, 1] takes into account the dynamical correlations between partons of different momenta in the nucleon. The ordinary parton distribution functions and form factors turn out to be the limiting cases and moments of GPDs, respectively. Of particular interest is the second moment of two unpolarized quark GPDs, which for the first time offers a possibility to determine the total angular momentum carried by the quarks in the nucleon [5]. Recent theoretical ideas indicate that GDPs are able to describe correlations between the longitudinal and transverse structure of the nucleon [6, 7]. For the case of coherent hard exclusive processes on nuclei it was pointed out very recently [8] that information about the distribution of energy, pressure, and shear forces inside nucleons and nuclei become accessible.

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DEEPLY–VIRTUAL COMPTON SCATTERING

In deeply–virtual Compton scattering (DVCS) a photon with large virtuality Q^2 is absorbed by a parton inside the nucleon and a real photon is produced. This process is considered to be the theoretically cleanest way to access GPDs. The DVCS cross section can be obtained through a measurement of the exclusive photon production cross section after subtracting the background from the Bethe–Heitler (BH) process which has an identical final state and is calculable exactly in QED. First results on the DVCS cross section at high energies have been published recently by H1 [9] and ZEUS [10]. At the lower energies of HERMES at DESY and CLAS at Jlab, the DVCS cross section is expected to be much smaller than the BH cross section and thus a measurement with sufficient precision is not yet feasible. However, the DVCS amplitudes are directly accessible through the interference between the DVCS and BH processes. The leading–order and leading–twist interference term [11]

$$I = \pm \frac{4\sqrt{2}}{t\,Q\,x_B} \frac{m_p\,e^6}{\sqrt{1-x_B}} \times \left[\cos\phi \, \frac{1}{\sqrt{\varepsilon(\varepsilon-1)}} \mathrm{Re}\,\tilde{M}^{1,1} - P_l \sin\phi \sqrt{\frac{1+\varepsilon}{\varepsilon}} \mathrm{Im}\,\tilde{M}^{1,1} \right] \quad (1)$$

depends on the charge and the polarization of the incident lepton, where +(-) in front of the expression corresponds to a negatively (positively) charged lepton with polarization P_l. Here m_p represents the proton mass, t the square of the four–momentum transfer to the target, $-Q^2$ the virtual–photon four–momentum squared, x_B the momentum fraction of the nucleon carried by the struck quark, and ε is the polarization parameter of the virtual photon. The azimuthal angle ϕ is defined as the angle between the lepton scattering plane, i.e. the plane defined by the incoming and the outgoing lepton trajectories, and the photon production plane made up by the virtual and real photons. The linear combination of DVCS amplitudes $\tilde{M}^{1,1}$ can be expressed as a linear combination of GPDs convoluted with hard scattering amplitudes.

Appropriate cross section asymmetries allow the separate access to the real and imaginary part of $\tilde{M}^{1,1}$. The beam–spin asymmetry (BSA)

$$A_{LU}(\phi) = \frac{1}{<|P_l|>} \frac{\overrightarrow{N}(\phi) - \overleftarrow{N}(\phi)}{\overrightarrow{N}(\phi) + \overleftarrow{N}(\phi)} \sim \sin\phi \,\mathrm{Im}\,\tilde{M}^{1,1} \quad (2)$$

is proportional to the imaginary part of $\tilde{M}^{1,1}$, where the average polarization of the beam is given by $<|P_l|>$ and $\overrightarrow{N}$ ($\overleftarrow{N}$) represents the normalized yield for positive (negative) beam helicity. The subscripts L and U denote a longitudinally polarized beam and an unpolarized target. Measurements of the BSA on the proton have already been carried out by HERMES [12] and CLAS [13]. The new preliminary result on the proton based on HERMES data collected in 2000 is shown in the left panel of figure 1. The asymmetry indeed shows the expected $\sin\phi$ modulation. Note that although the average kinematic values are slightly different compared to those from the already published BSA from the 1996/97 running period [12], the results are consistent with each other.

Recently, the first measurement of the beam–charge asymmetry, accessing the real part of the same combination of DVCS amplitudes, has been carried out at HERMES [14] via the scattering of positron and electron beams off an unpolarized hydrogen target.

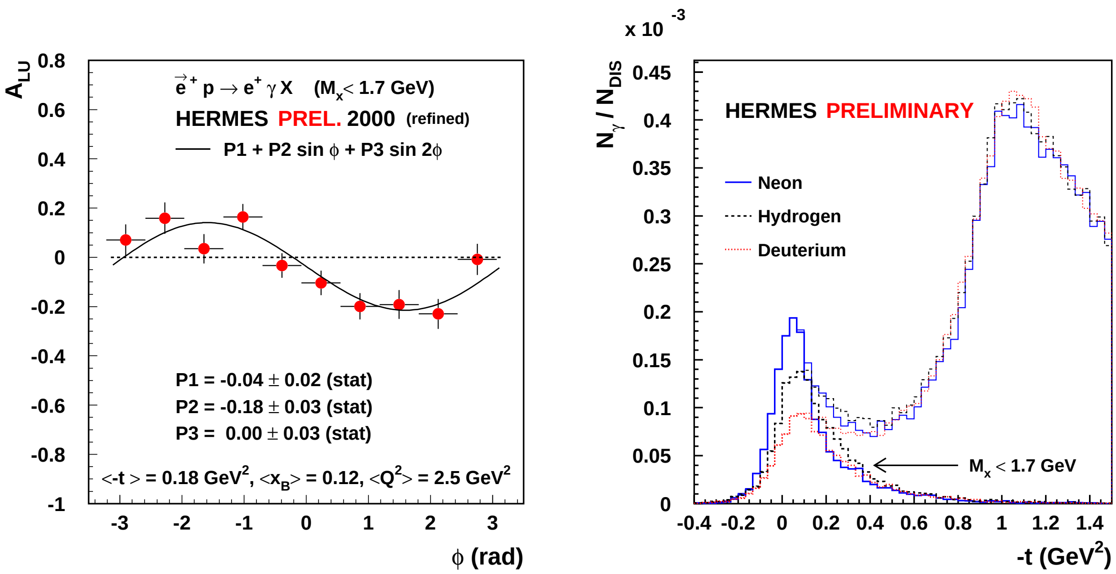

FIGURE 1. Left panel: Beam–spin asymmetry $A_{LU}(\phi)$ for the hard exclusive electroproduction of photons off the proton. Exclusive events are defined through the missing mass constraint $M_x < 1.7$ GeV. Right panel: $-t$ distribution of single-photon yields for neon, deuterium and hydrogen normalized to the number of DIS events. The exclusive events ($M_x < 1.7$ GeV) are shown separately.

DVCS ON NUCLEI

The data presented in the following have been accumulated by the HERMES experiment [15] at DESY during the 2000 running period. The HERA 27.6 GeV positron beam was scattered off polarized and unpolarized deuterium and unpolarized neon gas targets. Both the unpolarized and the spin–averaged polarized target data have been used in this analysis. Selected events contained exactly one photon and one charged track identified as the scattered positron. The kinematical requirements were $Q^2 > 1$ GeV^2, $W^2 > 4$ GeV^2 and $\nu < 23$ GeV. Here W denotes the photon–nucleon invariant mass and ν is the virtual–photon energy. The angle between the real and the virtual photon was required to be within 2 and 70 mrad. In the right panel of figure 1 the normalized yield of single photon events is shown versus $-t$ for neon and deuterium in comparison to hydrogen. Note that negative values of $-t$ appear due to the finite resolution of the spectrometer. Since the recoiling nucleus is not detected in the HERMES spectrometer, the missing mass $M_x = \sqrt{(q+P-k)^2}$ is calculated from q, P and k, the four–momenta of virtual photon, target nucleus and real photon, respectively. For this analysis the target mass is set to the proton mass in order to keep the same $M_x < 1.7$ GeV definition for exclusive events regardless of the target. The cross section for the exclusive events is dominated by the BH contribution, i.e. when going from nucleon to nuclei it increases with the square of the charge diminished by the form factor squared. This explains the differences in the single–photon yield for the different targets at small values of $-t$, i.e. for exclusive events as shown in the right panel of figure 1.

In figure 2 the azimuthal dependences of the BSAs on deuterium and neon are shown

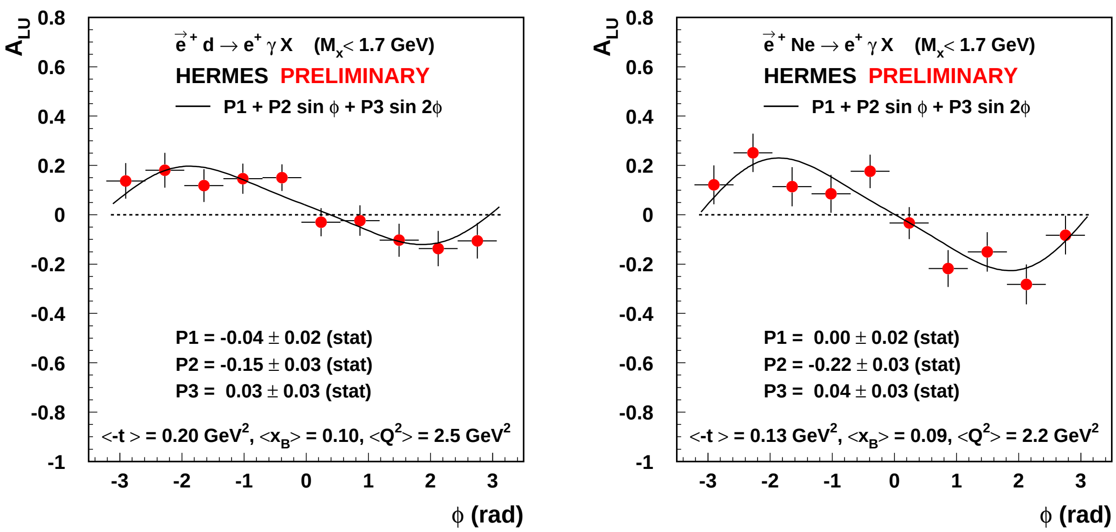

FIGURE 2. Beam–spin asymmetries $A_{LU}(\phi)$ for the hard electroproduction of photons off deuterium (left panel) and neon (right panel) for events with a missing mass $M_x < 1.7$ GeV.

for events with a missing mass M_x below 1.7 GeV. At the given average kinematics as indicated in the plots, the data exhibit the expected $\sin\phi$ behavior represented by the fit to the function $P_1 + P_2\sin(\phi) + P_3\sin(2\phi)$. Note that x_B is calculated using the proton mass, i.e. $x_B = Q^2/2m_p\nu$. As an independent method the $\sin\phi$–weighted moments

$$A_{LU}^{\sin\phi} = \frac{2}{\overrightarrow{N} + \overleftarrow{N}} \sum_{i=1}^{\overrightarrow{N}+\overleftarrow{N}} \frac{\sin\phi_i}{(P_l)_i} \tag{3}$$

are shown in figure 3 versus the missing mass M_x. The moments are non–zero only in the exclusive region and integrating $A_{LU}^{\sin\phi}$ up to $M_x < 1.7$ GeV yield the same results as the fits for the parameter P_2. Note, that negative values of the missing mass are again a consequence of the finite momentum resolution of the spectrometer, in that case $M_x = -\sqrt{-M_x^2}$ was defined. In contrast to the case of DVCS on the proton, DVCS on the deuteron has received little consideration in the literature [16, 17, 18]. The BSA on the deuteron is expected to be slightly smaller [17] than the one on the proton. This is in agreement with our results when comparing the left panels in figure 1 and figure 2, where the BSAs on the proton and the deuteron, achieved in a similar average kinematic region, amount to -0.18 ± 0.03 (stat) ± 0.03 (sys) and -0.15 ± 0.03 (stat) ± 0.03 (sys), respectively. However, present theoretical predictions assume $Q^2 \geq 4$ GeV^2 in order to avoid possible large target–mass corrections which have not yet been calculated for spin–1 targets. In addition, since at HERMES the recoiling nucleus is presently not detected, the ratio of coherent to incoherent production cannot be directly inferred from the measurement. For nuclei heavier than the deuteron no predictions are available yet.

In summary, beam–spin asymmetries in the hard electroproduction of real photons off nuclei have been measured for the first time. Sizeable asymmetries of $-0.15 \pm$

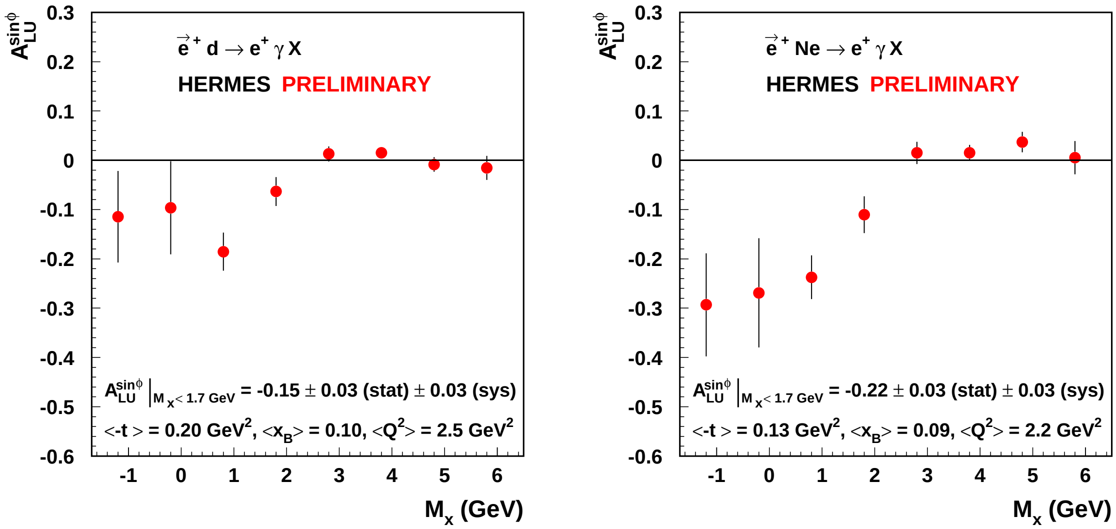

FIGURE 3. $\sin\phi$–weighted moments $A_{LU}^{\sin\phi}$ for the hard electroproduction of photons off deuterium (left panel) and neon (right panel) versus the missing mass M_x.

0.03 (stat) ± 0.03 (sys) and -0.22 ± 0.03 (stat) ± 0.03 (sys) have been found in the exclusive region for deuterium and neon, respectively. The corresponding asymmetry on the proton amounts to -0.18 ± 0.03 (stat) ± 0.03 (sys). This value is in agreement with the already published data from an earlier running period.

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